UNIVERSITI PUTRA MALAYSIA

PHOSPHORUS IN ACID SOILS AMENDED WITH ORGANIC AND INORGANIC INPUTS: ITS STATUS AND INTERACTIONS

ABDUL RAHMAN BAH

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By

ABDUL RAHMAN BAH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

March 2002

DEDICATION

This work is dedicated to my parents:

ALPHA AMADU JAWOH BAH and NENEH UMU HAWA BAH

Abstract of the thesis presented to the Senate of the Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

PHOSPHORUS IN ACID SOILS AMENDED WITH ORGANIC AND INORGANIC INPUTS: ITS STATUS AND INTERACTIONS

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March 2002

Chairperson: Professor Dr. Zaharah Abdul Rahman

Faculty: Agriculture

The combined use of green manures (GMs) and phosphate rocks (PRs) could be a more efficient and sustainable approach in alleviating P deficiency in acid tropical soils. Understanding the chemical and biological processes or interactions influencing P dynamics in such systems is therefore, vital for adaptation to different cropping systems.

The effect of GMs and P fertilizers on two acid soils (Bungor and Selangor series) was investigated in a laboratory incubation study and two glasshouse experiments using conventional and radioisotope techniques. The treatments were a factorial combination of GMs (legumes - *Calopogonium caeruleum*, *Gliricidia sepium*, and a non-legume *Imperata cylindrica*) and P fertilizers (PRs from North Carolina, China and Algeria, and triple superphosphate), completely randomized with up to 4 replications. Olsen P, biomass P, exchangeable Ca, mineral N and acidity were monitored in the soils for 16 months, and P in the soil fractions/pools was quantified at the end of the

incubation. The relative contribution of the sources to P uptake and utilization by Setaria grass (*Setaria sphacelota*) was determined by the ^{33}P-^{32}P double isotope labeling and ^{32}P isotope dilution techniques.

The P fertilizers had little effect on available P, whilst the sole GMs and GM+P amendments altered it in two phases. An initial lag phase with depressed P levels in the first 16 weeks coincided with the buildup of NH_4-N (up to 1000 mg N kg^{-1}) and exchangeable Ca, elevated soil pH (up to 2.3 units), up to 5-fold increase in microbial P, and significant GM×P×Soil interactions. The second phase showed higher available P, and much lower NH_4-N, biomass P, pH. The GMs also reduced sorption capacity (by over 84%), increased available P 6-10 times, and also the Al-P and Fe-P fractions. They decreased P in the unavailable pool, the organic-P fraction and 50-75% of Ca-P in PR-amended soils. The GM contribution to P uptake was small (<5%) and the utilization was < 1%, but they caused much higher total P uptake than the P fertilizers alone (more than 160%). They improved fertilizer-P utilization from < 20% to > 50%. They significantly enhanced soil P contribution in the following order: Gliricidia<Imperata<Calopogonium. Unexpectedly, the low quality Imperata GM also increased P availability and uptake when integrated with reactive PRs, probably by improving soil moisture content. Calcium concentration, GM quality, microbial turnover, and soil P mobilizing capacity regulated P dynamics in these systems.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

FOSFORUS DALAM TANAH ASID DIRAWAT DENGAN BAHAN ORGANIK DAN TAK ORGANIK: STATUS DAN INTERAKSI

Oleh
ABDUL RAHMAN BAH

Mac 2002

Pengerusi: Profesor Dr. Zaharah Abdul Rahman

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Mencampuran bahan organik (BO) dan batuan fosfat (BF) ke dalam tanah boleh menjadi satu cara berkesan dan mampan untuk memperbaiki kekurangan P dalam tanah-tanah asid di kawasan tropika. Fahaman terhadap proses-proses kimia dan biologi dan interaksi diantara kedua-duanya terhadap dinamik P dalam sistem tersebut adalah perlu sebelum kaedah ini boleh diadaptasikan didalam pelbagai sistem tanaman.

Kitaran P dalam dua tanah asid (Siri Bungor dan Siri Selangor) yang dirawat dengan BO dan BF telah dikaji di dalam satu eksperimen makmal dan dua eksperimen rumakaca menggunakan kaedah-kaedah konvensional dan radioisotop. Rawatan digunakan ialah kombinasi faktorial BO (kekacang – *Calopogonium caeruleum, Gliricidia sepium,* dan satu bukan kekacang *Imperata cylindrica*) dan baja-baja P (BF dari North Carolina, Cina dan Algeria, dan baja superfosfat tripel), yang diatur secara rawak lengkap dengan 4 replikasi. P-Olsen, biomasa-P, Ca tukarganti, N mineral dan keasidan tanah telah diukur selama 16 bulan. Diakhir masa pemeraman ini, pecahan P dalam tanah di

tentukan. Sumbangan relatif punca baja P tehadap P diserap dan digunakan oleh rumput Setarai (*Setaria sphacelata*) ditentukan dengan kaedah-kaedah penglabelan dwi-isotop ^{32}P-^{33}P, dan pencairan isotop ^{32}P.

Sumber baja P yang digunakan tidak menunjukkan kesan ketara terhadap P kedapatan, manakala BO dan BO+P mengubah P kedapatan dalam dua fasa. Fasa permulaan menunjukan tahap P yang menurun pada 16 minggu pertama, di mana fasa ini juga menunjukkan peningkatan NH_4-N (sehingga 1000 mg N kg^{-1}) dan Ca tukarganti, pH tanah meningkat (sehingga 2.3 unit), peningkatan sehingga 5 kali ganda, biomasa P dan interaksi yang ketara diantara BO$\times$P$\times$tanah. Fasa kedua menunjukkan peningkatan kedapatan, dan P tanah, NH_4-N, biomassa P dan pH yang menurun. Bahan organik juga didapati menurunkan keupayaan pengikatan P ($>$ 84%), meningkatkan P kedapatan 6-10 kali ganda, dan juga pecahan--pecahan Al-P dan Fe-P. Bahan organic juga boleh mengurangkan P tidak kedapatan, pecahan P organik dan 50-75% daripada pecahan Ca-P dalam tanah yang di rawat dengan BF. Sumbangan bahan organic terhadap P kedapatan adalah kecil ($<$5%) dan keberkesanannya ialah $<$ 1% tetapi, ia dapat meningkatkan jumlah P yang diserap dibandingkan dengan baja P sahaja ($>$ 160%). Ia dapat meningkatkan keberkesanan P dari $<$ 20% to $>$ 50%, dan meningkatkan dengan ketara sumbangan P tanah mengikut turutan Gliricidia $<$ Imperata $<$ Calopogonium. Imperata, sebagai bahan organik berkualiti rendah, telah dapat meningkat P kedapatan dan P diserap apabila dicampurkan dengan BF reaktif, berkemungkinan kesan daripada peningkatan kelembapan tanah. Kepekatan Ca, kualiti BO, kitarsemula mikrob dan keupayaan pergerakan P dalam tanah adalah faktor-faktor yang mengawal dinamik P dalam sistem ini.

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I certify that an Examination Committee met on 30th March 2002 to conduct the final examination of Abdul Rahman Bah on his Doctor of Philosophy thesis entitled "Phosphorus in Acid Soils Amended with Organic and Inorganic Inputs: Its Status and Interactions" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

ABDUL RAHMAN BAH

Date: 08 MAY 2002

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CHAPTER I

INTRODUCTION

Phosphorus deficiency is a major factor limiting crop production in tropical areas due to the prevalence of highly weathered Ultisols and Oxisols, which make up about 43% of the land area (Sanchez and Uehara, 1980; Sanchez and Logan, 1992). These soils have low base saturation, toxic levels of Al and are generally low in nutrient reserves, especially of N and P (Sanchez and Uehara, 1980). Additionally, they can fix large quantities of applied P due to the high proportion of sesquioxides, the dominance of 1:1 clays and their medium-to-fine texture (Juo and Fox, 1977; Schwertmann and Herbillon, 1992; Frossard et al., 1995). Phosphorus is required for the efficient uptake and utilization of N, and it is also vital for many plant metabolic processes (Brady and Weil, 1999). This implies that deficiency in this nutrient can severely disrupt normal plant growth and reproduction, which eventually translates to drastic reduction in crop yields. Therefore, increasing crop productivity in the tropics is mostly dependent on how efficiently P is managed in agro-ecosystems.

Currently, traditional farming systems in the tropics have a much shorter fallow component because of greater demographic pressure. As fertilizer usage in these systems is quite uncommon, intensive cultivation activities often lead to deterioration in soil fertility, and ultimately land degradation. Moreover, inadequate P nutrition also results in sparse vegetation cover during the short fallow periods. This exposes the soil to the direct impact of the heavy rains common in tropical areas, and hence to greater loss of the topsoil by erosion. This subsequently results in serious pollution problems, which can jeopardize drinking water, endanger aquatic life and even affect the operation of dams and irrigation facilities. The problem becomes more widespread and severe as additional marginal lands are brought under cultivation and the cycle of degradation is repeated.

Recent strategies proposed to mitigate P deficiency include a large one-time fertilizer gift to replenish soil P, followed by regular maintenance applications for a few seasons (Buresh et al., 1997; Sanchez et al., 1997). The massive P application is designed to permanently saturate the sorption sites and provide P for crop uptake. The stock that provides P over a period of 5-10 years is referred to as 'soil P capital' whilst the P available during an annual cropping cycle is called 'liquid P' (Sanchez et al., 1996; Buresh et al., 1997). However in most cases, the use of soluble P fertilizers in the management of soil fertility in the tropics has proved to be uneconomical, mainly due to the costs involved and the low utilization efficiencies emanating from high P fixation (Juo and Fox, 1977; Iyamuremye and Dick, 1996). In addition, there are enormous distribution problems involved because of poor infrastructure, and sometimes, complete unavailability of these fertilizers. Furthermore, the dire economic circumstances of people in these areas make the cost of high analysis fertilizers prohibitive for most farmers. This is exacerbated by depressed commodity prices and the current policy of eliminating fertilizer subsidies by governments. Other important factors include the deleterious environmental effects associated with the use of these materials, especially under the high rainfall conditions common in this climatic zone.

The direct application of phosphate rocks (PRs) has shown great promise as a cheap and environmentally benign source of P in acid soils (Chien et al., 1980; Rajan et al., 1996). However, in many cases the effectiveness of these materials is very much restricted by their low reactivity. Therefore, various techniques have been used to improve their efficiency. The most attractive among these are the ones incorporating organic materials, for instance composting PRs with organic materials is reported to improve their effectiveness tremendously (Ikerra et al., 1994; Yang et al., 1994). In the same way, green manures (GMs) have been observed to increase the action of less reactive PRs (Zaharah and Bah, 1997). The extent of this effect was very much dependent on the biochemical characteristics of the GMs, especially the C-to-P ratio. Organic ligands and acids released during GM decomposition (Swift et al., 1979) are thought to play a key role in improving the solubility of the PRs (Chien, 1979). However, more information is required to fully understand the magnitude and duration of the influence of nutrient interactions on P release from the PRs, and its overall availability in the soil-GM-PR system. In general, integrating P fertilizers with high quality organic inputs is known to improve their efficiency by